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INCREASED OIL PRODUCTION AND RESERVES UTILIZING SECONDARY/TERTIARY RECOVERY TECHNIQUES ON SMALL RESERVOIRS IN THE PARADOX BASIN, UTAH

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Objectives

The primary objective of this project is to enhance domestic petroleum production by demonstration and technology transfer of an advanced oil recovery technology in the Paradox basin, southeastern Utah. If this project can demonstrate technical and economic feasibility, the technique can be applied to about 100 additional small fields in the Paradox basin alone, and result in increased recovery of 150 to 200 million bbl of oil. This project is designed to characterize five shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation and choose the best candidate for a pilot demonstration project for either a waterflood or carbon dioxide-(CO_2-) flood project. The field demonstration, monitoring of field performance, and associated validation activities will take place in the Paradox basin within the Navajo Nation. The results of this project will be transferred to industry and other researchers through a petroleum extension service, creation of digital databases for distribution, technical workshops and seminars, field trips, technical presentations at national and regional professional meetings, and publication in newsletters and various technical or trade journals.

Summary of Technical Progress

Three activities continued this quarter as part of the geological and reservoir characterization of productive carbonate buildups in the Paradox basin focusing on Runway field, San Juan County, Navajo Nation, Utah (Fig. 1): (1) reservoir modeling, (2) CO_2 flood performance prediction, and (3) technology transfer.
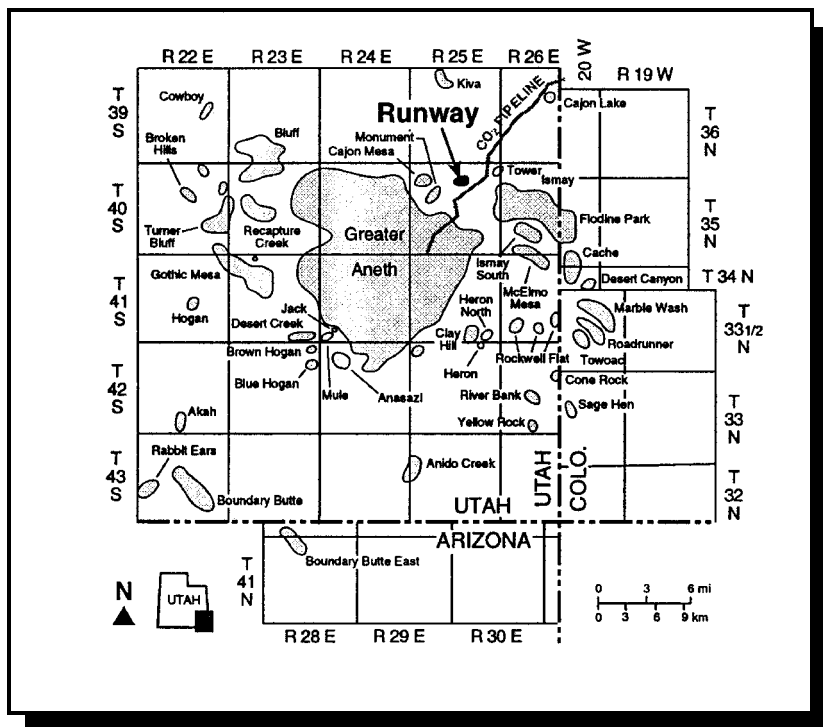

Fig. 1. Location of Runway field (dark shaded area with name in bold type) in the southwestern Paradox basin on the Navajo Nation, San Juan Co., Utah.

Reservoir Modeling, Runway Field

The significant spatial heterogeneity exhibited by both the lithotypes and the Desert Creek reservoir properties at Runway field required design and development of a multi-stage procedure for incorporating the variation known to exist from outcrop analogues into the reservoir model. Based on detailed examination of the cores and log data, and field observations from the Lower Ismay outcrop analogues, it was determined that a 50-layer geostatistical model would adequately capture the lithologic variability in the platform, mound-core, and supra-mound intervals.[1-3]

Observed lithologic, porosity, and permeability data from the three Runway wells were incorporated into the layering at the well locations. These model "conditioning" data were fixed throughout the subsequent modeling process.

Although the mound-core interval of the Runway Desert Creek reservoir is predominantly phylloid algal and bryozoan limestones, the overlying supra-mound dolomites and limestones exhibit a variety of lithotypes. A series of ten distinct lithotypes was identified within the Desert Creek reservoir. These lithotypes include carbonate mudstones, packstones/wackestones, grainstones, mound-building algal and bryozoan limestones, and solution collapse breccias. Several lithotypes are characterized by enhanced porosity and/or dolomitization.

The size and shape of the mound build-up area, the inferred areal extent of lithotype architectural bodies known to be present in the reservoir, and the constraints imposed by numerical modeling provided the framework for defining the areal grid for the Runway reservoir characterization and simulation model (Fig. 2). This model consists of 36 rows and 42 columns of grid cells, each measuring 180 ft square (Fig. 2). the 42x36 areal grid just spans the reservoir build-up, encompassing an area of 1125 ac.

The internal architecture of the Desert Creek reservoir was modeled between the wells using a marked-point (Boolean) process for emplacement of the ten constituent lithotypes (Fig. 3). In the mound-core interval, the phylloid algal and bryozoan limestones were emplaced deterministically, corresponding to the seismic buildup isolith. A total of 20 preliminary geostatistical models were generated using this procedure, for later sensitivity studies of the impact of reservoir continuity on production performance.
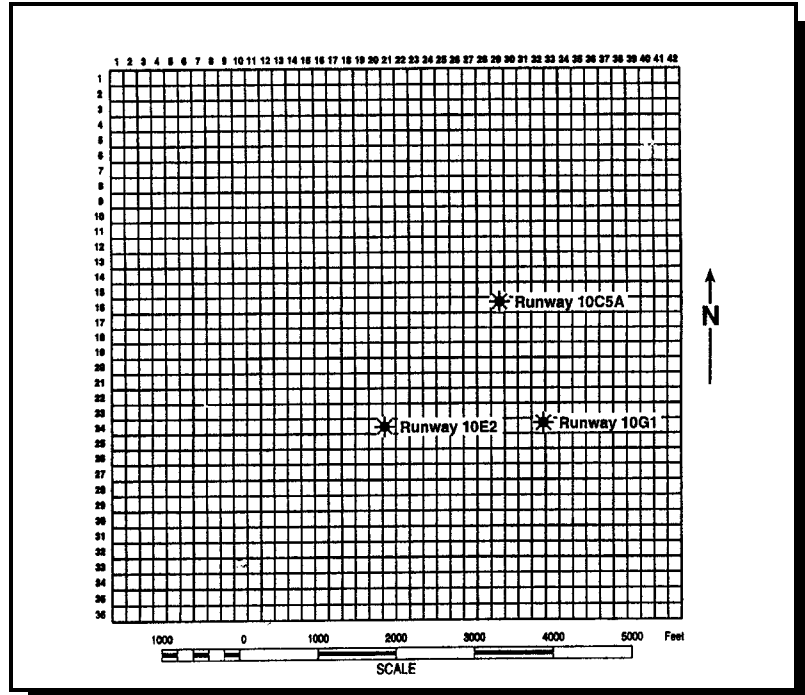

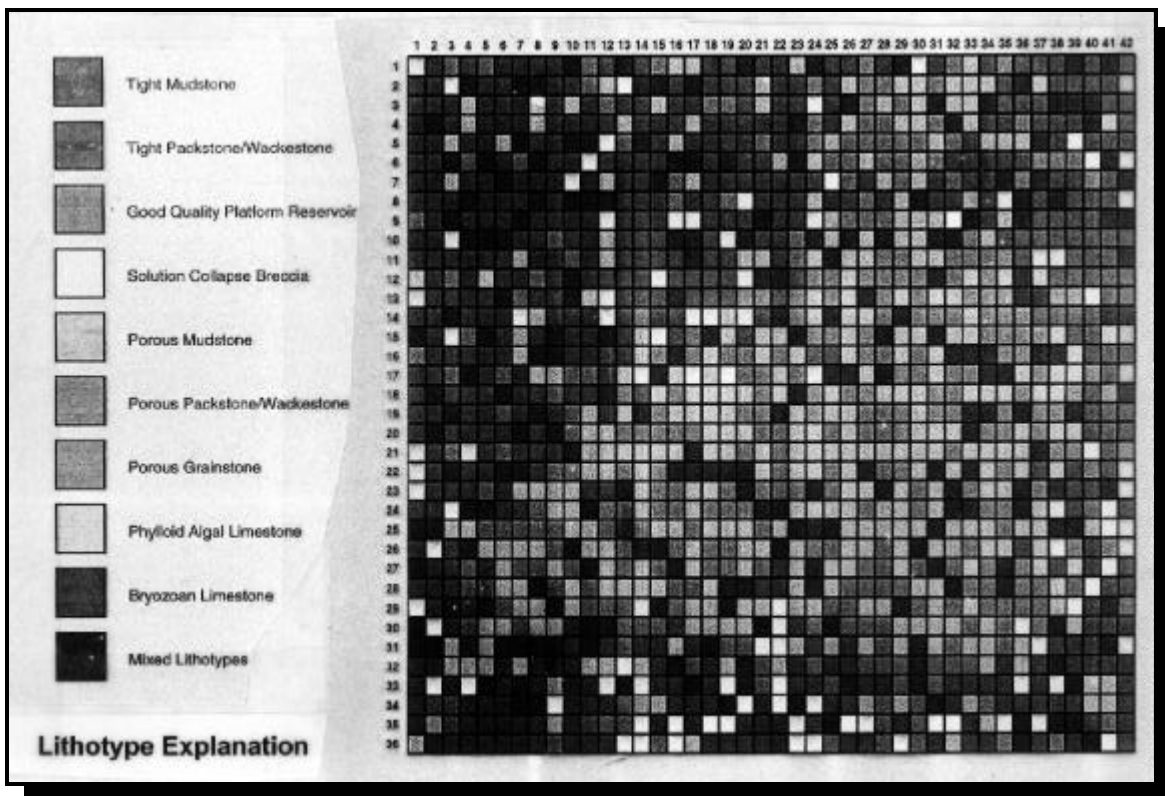Fig. 2. Runway field simulation grid and well locations.

Fig. 3. Spatial distribution of lithotypes at Layer 4 (supra-mound interval) from the 17-layer geostatistical Runway reservoir simulation model.
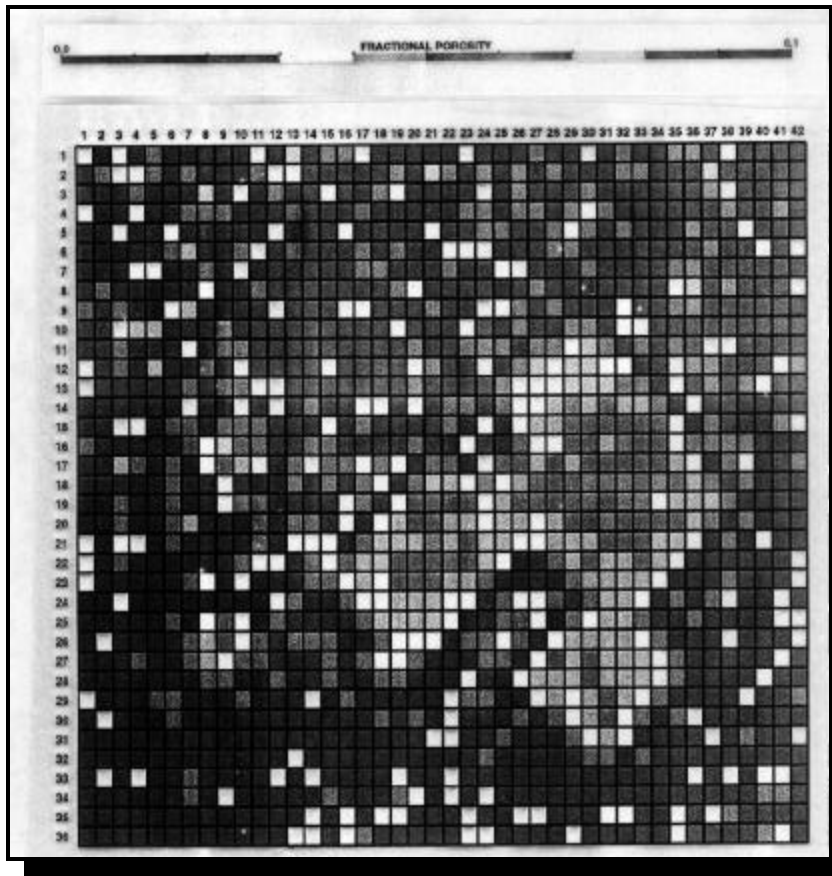
Fig. 4. Spatial distribution of porosity (fractional) at Layer 4 from the 17-layer geostatistical Runway reservoir simulation model.

The initial architectural model was modified by pair-wise exchange of gridblocks to fit porosity constraints of both local spatial variation and overall (global) average porosity distribution grid derived from seismic amplitudes (Fig. 4). The pair-wise, block-exchange process for simulating Desert Creek reservoir porosity between the Runway wells was carried out using the well-known stochastic relaxation technique, "simulated annealing."

Several features of the 50-layer geostatistical models are noteworthy. First, the platform, mound-core, and supra-mound intervals are clearly distinguished by the continuous development of the highly permeable phylloid algal and bryozoan limestones in the mound core, contrasted with the heterogeneous, less permeable but more porous mixed lithotypes in the underlying platform interval, and draped over the mound core in the supra-mound interval (Fig. 5). Second, much of the off-mound area is occupied by carbonate mudstone, while most of the supra-mound interval directly above the mound core consists of non-mud lithotypes. This is in keeping with lithotypes distributions in the Runway wells and in the Lower Ismay outcrops. In contrast to the previously studied Desert Creek carbonate mound reservoir at Anasazi field (Fig. 1), the best quality supra-mound lithotype (porous grainstone) bodies are largely restricted to the mound area, and do not extend far out into the adjacent off-mound areas as detrital "aprons," as seen at Anasazi. This is consistent with the generally deeper water environment inferred from the presence of bryozoan limestones at Runway field.[1]

Finally, because of computer flow simulation runtime limitations, the number of layers in the Desert Creek reservoir model was reduced from 50 to 15. Sensitivity studies indicated that most of the variation in effective properties could be retained with careful scaling of porosity and permeability. Lithotypes were assigned to each of the 15-layer gridblocks according to the dominant lithotype in the corresponding 3.5 layers of the parent 50-layer geostatistical model. Porosity was volume-averaged for the 15-layer model, and effective permeability was computed by solution of the pressure equation using the field-scale reservoir simulator.
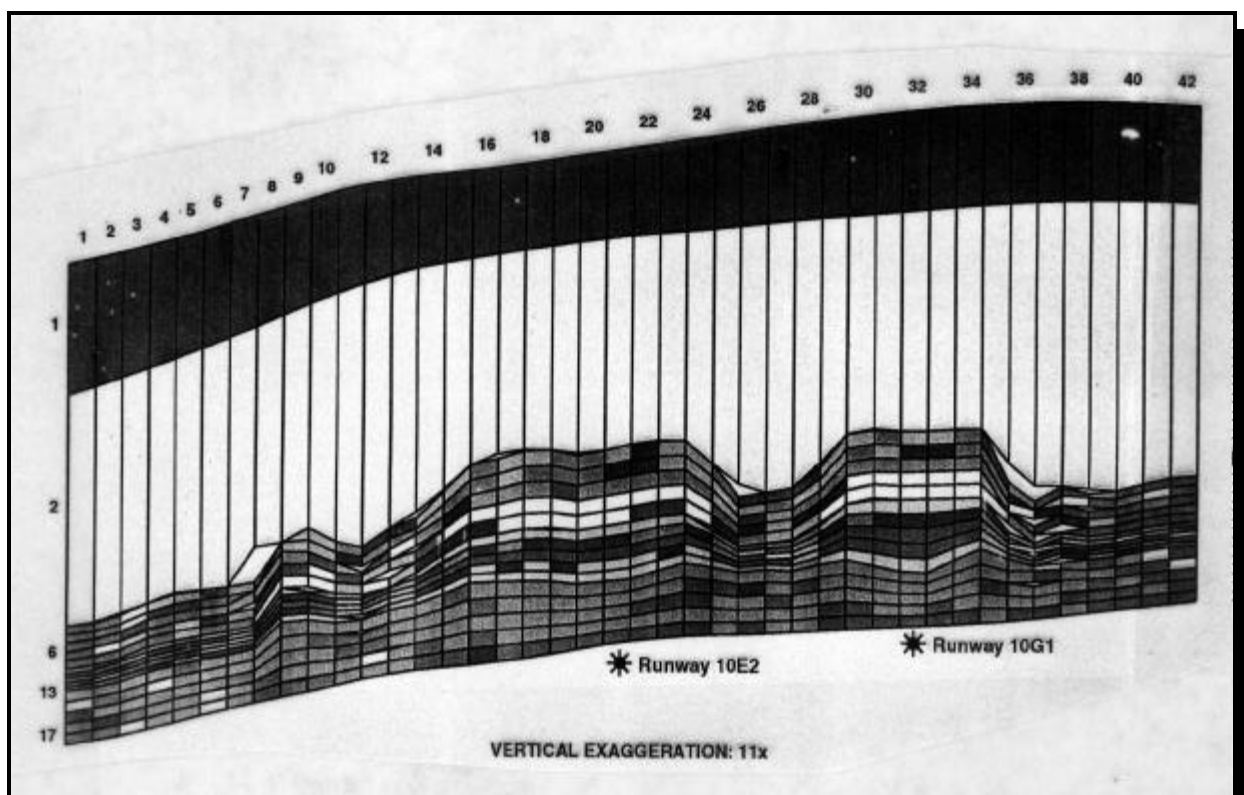
Fig. 5. East-west cross section, through the Runway Nos. 10E-2 and 10G-1 wells, of the 17-layer geostatistical Runway reservoir simulation model displaying the spatial distribution of lithotypes in the Desert Creek and Ismay zones. See Fig. 3 for explanation of lithotypes.

In addition to the Desert Creek carbonate mound reservoir, the lower dolomite in the Upper Ismay is perforated and under production in the Runway No. 10G-1 well. This separate Upper Ismay reservoir is isolated from the Desert Creek reservoir by as much as 115 ft of non-producing section comprised of the Desert Creek anhydrite, Gothic Shale, Lower Ismay carbonates, and Hovenweep Shale. In the final Runway reservoir model, the Upper Ismay reservoir is designated as Layer 1, and the intervening interval isolating the Desert Creek and Upper Ismay reservoirs is Layer 2; thus, the final model consists of a total of 17 layers.

Carbon Dioxide Flood Performance Prediction, Runway Field

General Description

Compositional simulation was used to history match (model) predicted production to actual past production performance of the Runway field and to predict the performance of continued primary depletion and various CO_2 floods. The simulation study employed a stochastically generated reservoir description with 12 different facies. The reservoir fluid was characterized via a 11-pseudo-component equation-of-state calibrated using CO_2-swelling tests conducted on crude oil from Anasazi field and the original black oil pressure-volume-temperature (PVT) data for Runway field.[4, 5] Gas-oil and water-oil relative permeability, capillary pressure, and rockpore volume compressibility data were

generated for the three principal productive facies: phylloid algal limestone, enhanced porosity packstones/wackestones, and bryozoan limestone.

Simulation History Match and CO_2 Flood Prediction

The compositional study consists of history matching and prediction phases. Key history match variables included individual well and field gas production rates and periodically measured reservoir pressure values. Once the simulator was calibrated by obtaining a suitable match of production data it was used to predict the performance of the reservoir under continued primary production and CO_2-flood operations.

Carbon-dioxide flood performance predictions for several different operating conditions and well configurations have been completed. Figure 6 compares primary depletion performance versus CO_2 flooding using two horizontal injection wells. For this example the incremental oil recovery over primary at January 1, 2012 is approximately 1.34 million stock tank bbl (MMSTB).

Oil and gas saturations were modeled for the start of CO_2 injection. Ten years of primary production has generated a variable free gas saturation (0-40%) as well as producing 825,000 stock tank bbl (STB) of oil. The simulator model also shows extensive gas segregation into the supra-mound interval.

Figure 7 illustrates the oil saturation distribution in the Ismay (upper layer) and Desert Creek (lower layer) zones at the start of CO_2 injection, based on a "cut away" through the Runway Nos. 10G-1 and 10E-2 production wells. The two injectors (shown in Fig. 7 as three-dimensional arrows pointing downward) are horizontal wells but the horizontal leg of each well is hidden from view. The upper most injector is placed along the northwestern flank of the mound and the lower most
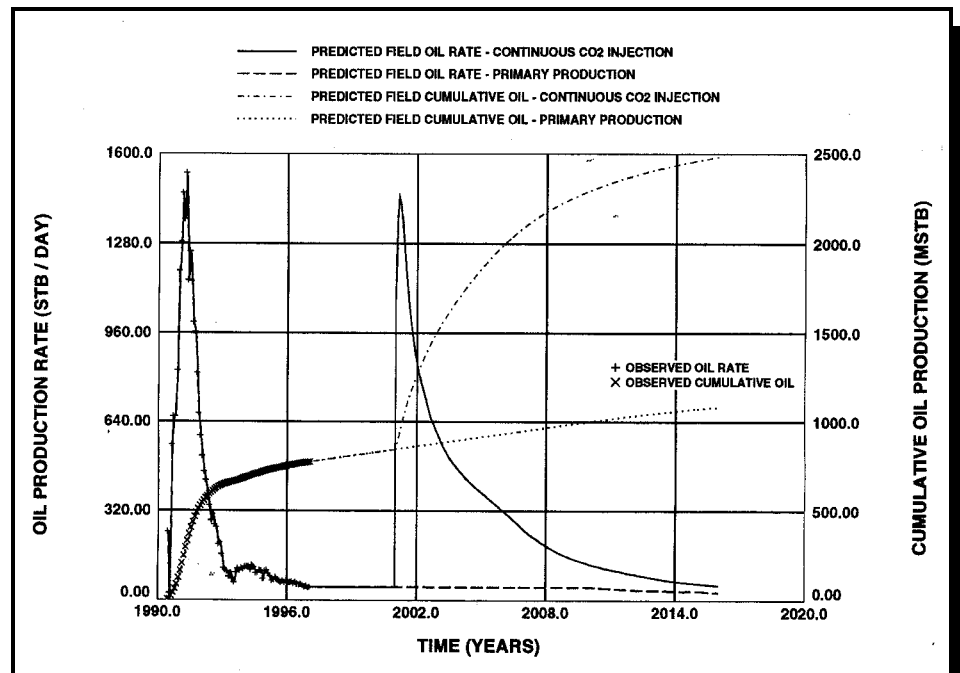

Fig. 6. Oil recovery - primary depletion versus continuous CO_2 flood injection/flood recovery, Runway field.
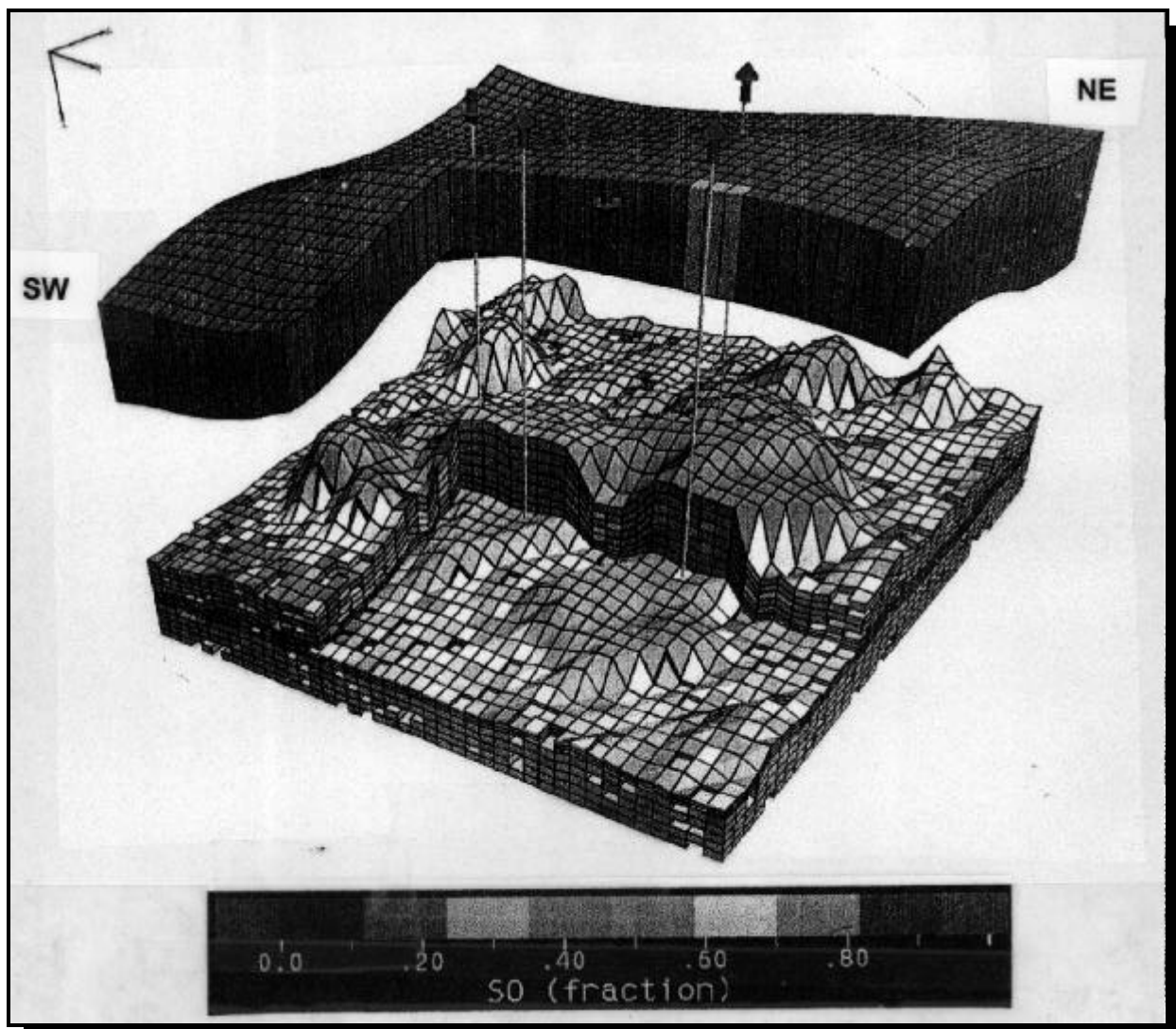
Fig. 7. Block diagram displaying reservoir oil saturation distribution at the start of CO_2 injection. Shown is a "cut away" through one of the proposed horizontal injector wells and the Runway Nos. 10G-1 and 10E-2 production well locations. SO (fraction) is the oil saturation.

injector is placed along the southeastern flank of the mound. Both injectors were completed in the supra-mound interval.

Figure 8 illustrates the oil saturation distribution after 4.5 years of CO_2 injection using two injectors. The figure shows two important points. First, reservoir pressurization redissolves all free hydrocarbon gas present at the start of injection, returning the majority of the reservoir to initial oil saturation values. Second, the volume of the reservoir contacted by the injected CO_2 shows a near zero residual oil saturation. This displaced oil is produced via the existing field production wells. Both the supra-mound and mound-core intervals have been swept by CO_2, but there is an uncontacted portion of the reservoir between the Runway Nos. 10G-1 and 10C-5A wells. This will be swept after additional CO_2 injection based on the simulation. The study also shows the extensive contact of
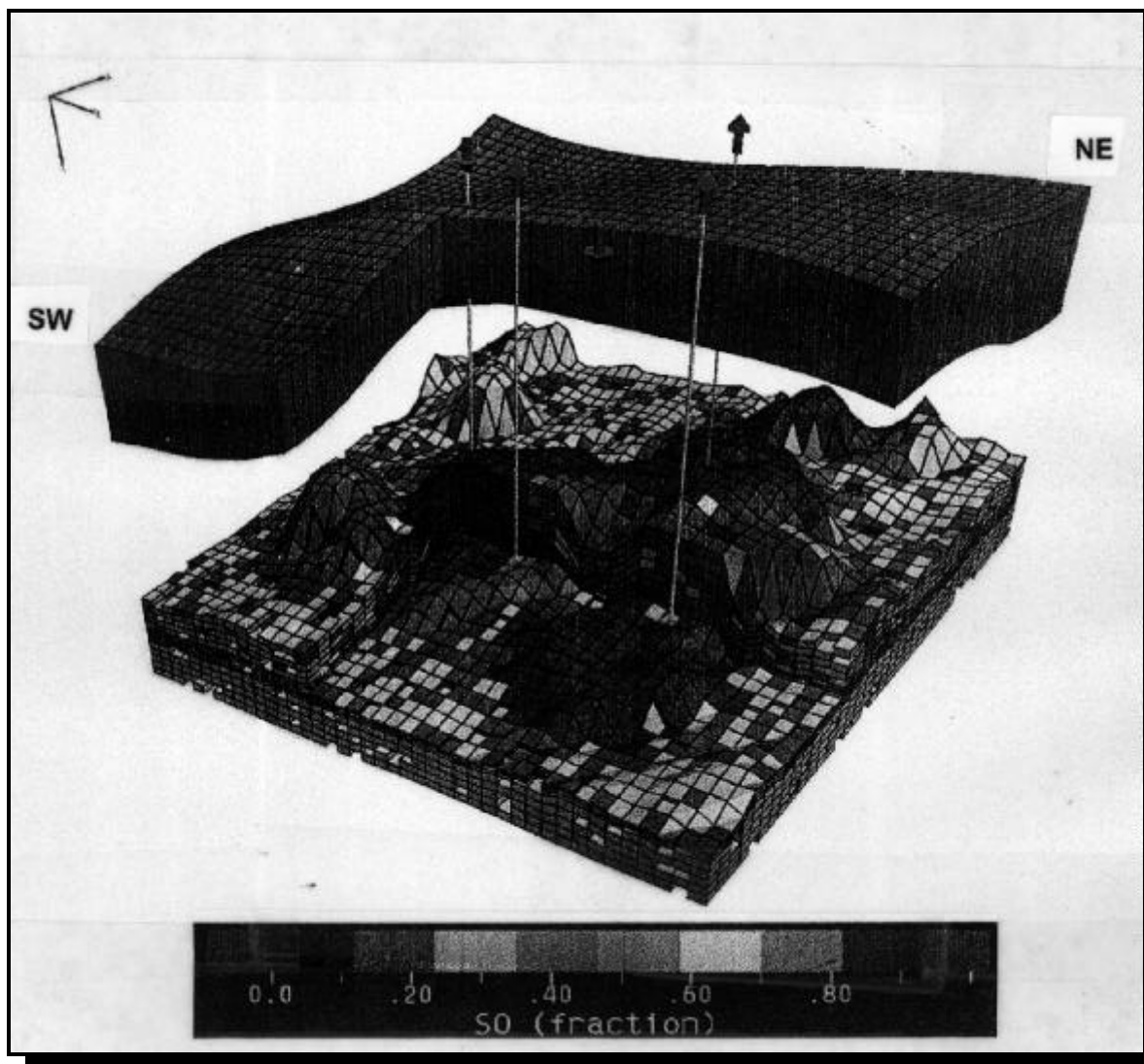
Fig. 8. Block diagram displaying reservoir oil saturation distribution after 4.5 years of CO_2 injection, Runway field.

reservoir volume by CO_2 (liquid phase mole fraction of CO_2) after 4.5 years of CO_2 injection. At the operating pressure level of 3000 pounds per square inch (psi), CO_2 and hydrocarbon are at or near miscible conditions. Thus, the oil displacement will be essentially complete (low residual oil saturation values).

Technology Transfer

Project material was displayed at the Utah Geological Survey booth during the American Association of Petroleum Geologists (AAPG) annual convention held in Salt Lake City, Utah, May 17-20, 1998. Paradox team members presented a paper describing reservoir modeling and flow simulation of the Runway field at the convention.[6] The project home page on the UGS Internet web

site (http://www.ugs.state.ut.us/paradox.htm) was updated with the latest quarterly technical report and project publications list.

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